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# Distraction Osteogenesis of the Midface

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The field of pediatric oral and maxillofacial surgery is continuing to evolve and is in a dynamic phase as our understanding of growth and development of the craniomaxillofacial complex expands. Bone regeneration and tissue engineering technologies have been developed to treat skeletal defects with reduced morbidity [1]. Distraction osteogenesis recently emerged as a technique that by its very nature allows changes to the vectors of growth and results in the genesis of new tissues [2]. It is a rapidly developing area with applications in the area of pediatric oral and maxillofacial surgery.

Distraction osteogenesis is a biologic process that promotes bone formation between cut osseous surfaces that are gradually separated by incremental traction [3]. This process is initiated when forces are applied to separate the segments and continues as long as the tissues of the callus that forms between the segments are stretched. Bone formation occurs parallel to the direction or vector of distraction. This process also initiates histiogenesis of the tissues surrounding the distracted bone: cartilage, ligaments, muscle, blood vessels, gingiva, and nerve tissue [2,4,5].

## History of midfacial distraction osteogenesis

Distraction osteogenesis as it applies to the midface is not a new concept. Dentists have used techniques that involve the application of tensile and compressive forces to the bones of the craniomaxillofacial skeleton for almost 300 years. According to Balaji [6], Fauchard described the use of an expansion arch as early as 1728, a custom-made metallic arch applied to the crowded maxillary dentition, to widen the arches to a more physiologic form. Wescott attempted to correct a crossbite by placing two double clasps on the maxillary bicuspid teeth and a telescopic bar to apply transverse force [6]. Similarly, Angell [7] expanded a maxillary arch by using a transverse jackscrew and clasps on the bicuspid teeth.

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Goddard is credited with standardization of the palatal expansion protocol with activation twice daily for 3 weeks followed by a period of stabilization [8]. Modern clinical distraction osteogenesis of the facial bones developed quickly once McCarthy applied the concept to mandibular lengthening in 1992 [9]. This development led to an explosion of clinical and research activity in the field of craniomaxillofacial distraction osteogenesis over the past decade [10].

## Distracting tubular long bones

The mechanical manipulation of bone segments dates as far back as Hippocrates, who described the use of external devices to apply traction to bone [11,12]. Codivilla [13] is credited with using an external skeletal traction apparatus after performing an oblique femoral osteotomy to accomplish the first lower extremity lengthening. The Siberian surgeon Gavril Ilizarov was the first to describe a tissue-sparing osteotomy and reliable distraction protocol that involved the long bones of the lower extremity in 1951 [11].

Ilizarov's protocol was unique and involved a 5- to 7-day latency period after the osteotomy. This critical rest period was followed with a period of distraction applied at a rate of 1 mm per day using four incremental distractions of 0.25 mm. The most critical aspect of the technique described by Ilizarov was maximal preservation of endosteum and periosteum using a procedure he termed "corticotomy." He described a method in which he divided two thirds of the cortical bone of the femur with a narrow osteotome and finally separated the bony segments from each other by rotational osteoclasis [3]. The gradual application of traction resulted in the tension-stress effect that can stimulate the genesis, regeneration, and active growth of living tissues as long as there is an adequate blood supply [4,11,12].

Distraction osteogenesis involves five distinct periods: osteotomy, latency, distraction, consolidation, and remodeling [3,4,11,12]. Osteotomy is the surgical separation of an intact bone into two segments. It results in a loss of continuity and mechanical integrity, which triggers the process of fracture healing. A reparative callus begins to form within and around the ends of the fractured bone segments.

Latency is the period during distraction osteogenesis that begins with osteotomy of the bone segments and ends with the onset of traction. Latency permits sufficient time to elapse for a callus to form between the osteotomized bone segments [3,4].

Distraction is the period during which traction is applied to the bony segments when new bone or, more precisely, a distraction regenerate is formed within the gap between the bony segments. Two parameters can be used to tailor the distraction process: rate and frequency. Gradual traction of the soft callus disrupts fracture healing, and the tensional stress stimulates changes at the cellular and subcellular levels [2–5]. These changes include increased proliferation of fibroblasts with an altered phenotypic expression that secrete collagen fibers parallel to the vector of distraction. Bone formation begins at the termini of the bony segments and progresses toward the center of the distraction gap [3].

Consolidation begins after termination of traction [11,12]. Consolidation permits mineralization and eventual corticalization of the newly formed bone in the distraction regenerate and must be substantially complete before removal of the distraction device.

Remodeling begins at the onset of functional loading of the distracted bone. The initial bony scaffold is reinforced by parallel fibered lamellar bone. Gradually the cortical bone and marrow cavity are formed. Remodeling of Haversian systems is the last process to occur before development of completely normal bone at the site of distraction. The process of remodeling can take more than 1 year [11,12].

## Distracting irregularly shaped membranous bones

Distraction osteogenesis can be applied to multiple sites in the midfacial skeleton in pediatric and adult populations. The application of the concepts described in limb lengthening and the distraction of tubular long (endochondral) bones, however, must be modified when applied to the irregularly shaped membranous bones of the midface [2]. Distraction osteogenesis can be used in several areas (Box 1), including the maxilla at the LeFort I, II, and III levels, the nasal and zygomatic bones, and the bones that comprise the cranium. Distraction osteogenesis can be applied to healed bone grafts in the craniomaxillofacial skeleton and to vertical and horizontal defects of the maxillary alveolus.

The devices required for distraction of each of these areas varies depending on the site and goals of treatment. Hardware may range from large external halo-like devices (Fig. 1) to much smaller appliances that resemble bone fixation plates (Fig. 2) to jackscrews that attach to the teeth (Fig. 3). The goals of treatment and the necessary vectors used in each of

**Box 1. Midfacial distraction device classification**

*External: bone-borne*
*Internal: subcutaneous*
*Intraoral*
- Extramucosal
  - Tooth-borne
- Submucosal
  - Bone-borne
  - Hybrid

*Classification according to distraction direction*
*Unidirectional*
*Bidirectional*
*Multidirectional*
*Classification according to site of midfacial distraction*
*LeFort I, II, III*
*Nasal bones*
*Zygomatic bones*
*Healed bone grafts*
*Maxillary alveolus*
- Transverse
- Vertical
- Horizontal

these regions are also distinct. The direction of distraction must be well planned. Certain devices allow distraction in more than one plane or vector (see Fig. 1). At times, two appliances may be used simultaneously; however, neither the devices themselves nor their vectors of distraction should be allowed to interfere with each other (Fig. 4).

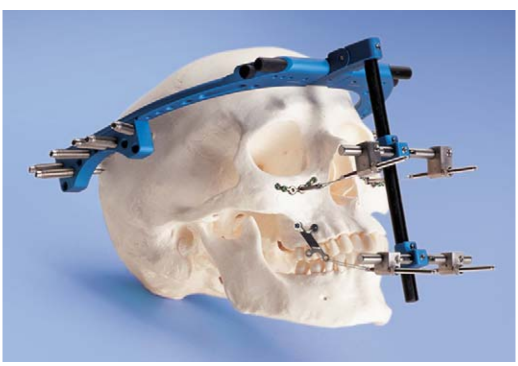

Fig. 1. A halo-like external frame device used to distract the retrusive midface (Biomet-Lorenz, Jacksonville, Florida). Such devices have become simple to apply, lightweight, and based on transcutaneous pin fixation to the skull. This device can be adapted to provide distraction vectors in more than one plane.

Fig. 2. Intraosseous devices configured like bone plates with a distractor rod between them are much smaller than their halo-like counterparts (KLS Martin, Jacksonville, Florida, USA).

## Indications

Distraction osteogenesis is a labor-intensive and technique-sensitive treatment modality and should be reserved for specific indications. Distraction osteogenesis of the midface has two main advantages over traditional osteotomies. It can produce larger movements, and it may be associated with less relapse than traditional osteotomies. Distraction osteogenesis should be used for significant bony movements in the treatment of conditions known to have high relapse rates after traditional forms of treatment.

Distraction osteogenesis can be repeated at different phases of life. In some cases the application of a halo to the skull and a few simple titanium plates screwed into the bones of the craniomaxillofacial skeleton may be less invasive than certain osteo-

Fig. 3. Traditional tooth-borne palatal distractor. Note diastemma between maxillary central incisors, which is site of the palatal distraction osteogenesis. Same as Fig. 5.

Fig. 4. Two devices are used to distract at the LeFort I level. The vectors of distraction of the devices must have minimal convergence so they do not interfere with each other (Synthes, Oberdorf, Switzerland).

tomies, and developing tooth roots can be avoided and left undamaged by the design of osteotomies.

Patients who have cleft lip and palate often require significant advancement of their midface at one or more LeFort levels. Maxillary advancement using traditional osteotomies may place these patients at risk for the development of velopharyngeal insufficiency [14,15]. It has been reported that this debilitating complication may be avoided for some of these patients if distraction osteogenesis is used to advance the maxilla [2,16], because it can leave the posterior dentition and velopharyngeal relationships undisturbed.

Distraction osteogenesis of the midface also may be applied to treat functional problems, such as obstructive sleep apnea and exposure keratitis and corneal scarring from proptosis [17–19].

## Risks associated with midfacial distraction

The risks associated with distraction osteogenesis of the midfacial structures are similar to the risks encountered with traditional osteotomies. Careful preoperative planning of the vector of distraction is essential to ensure that the distracted segment advances fully in the desired direction without interference from surrounding bony structures or teeth.

Swennen and colleagues [10] reported complications in 828 patients undergoing craniomaxillofacial distraction. Complications included mechanical problems, such as pin loosening caused by accidental trauma, device failure, minor local infections, infections of the skin surrounding percutaneous pins, premature consolidation, limited skeletal advancement, asymmetric advancement, ankylosis of zygoma and coronoid process, severe infection, damage to teeth, and tooth mobility.

## Distraction across the midpalatal suture

The age of the patient dictates the type of distraction that may be used to expand the maxilla. In growing children with a transverse deficiency of the maxilla and in whom the midpalatal suture has not yet fused, force analogous to physeal distraction used in orthopedics can be applied across the midpalatal suture [20]. Distraction of the midpalatal suture occurs in membranous bone across a suture, whereas physeal distraction is used in endochondral bones across an epiphyseal growth plate.

Rapid palatal expansion, also known as orthopedic rapid maxillary expansion, can be performed in girls before 15 years of age and in boys before 16 years of age [8]. If the palatal suture is fused then tipping of teeth occurs rather than transverse expansion of the maxilla [21].

Surgical widening of the maxilla must be used to correct transverse maxillary deficiency in patients with a fused midpalatal suture. This procedure has been termed surgically assisted rapid palatal expansion or surgically assisted maxillary expansion. Although it predates all other distraction osteogenesis procedures performed in the midface, it is often forgotten in the classification of midfacial distraction.

As with other distraction osteogenesis procedures, there are five distinct phases in surgical widening of the maxilla at the level of the midpalatal suture: osteotomy, latency, distraction, consolidation, and remodeling [3]. The osteotomy is performed at the LeFort I level and involves a variable combination of surgical separation of the midpalatal suture and osteotomy of the lateral and medial nasal walls, nasal septum, vomer, and pterygomaxillary junction [21–23]. The exact combination of osteotomies varies among authors [24–31]. The latency period is generally 1 to 2 days. Distraction is performed using a transverse jackscrew connected to attachments placed on the first molar and bicuspid teeth. Distraction is performed with a frequency of two increments of 0.5 mm per day (1 mm/d) until the maxilla has been widened sufficiently. The distraction device is kept in place for 3 months to allow for

Fig. 5. Note intersegmentary bone formed in the maxillary midline after surgically assisted rapid palatal expansion on this occlusal radiograph. The device has been left on after the distraction phase to serve as a retainer during the consolidation phase.

consolidation. Active orthodontic treatment can resume during the remodeling phase.

The surgically assisted rapid palatal expansion or surgically assisted maxillary expansion procedure produces intersegmental bone (Fig. 5) and creates a stable widening of the maxillary arch, even when it is significantly constricted (Fig. 6A, B). As in other forms of distraction osteogenesis, distraction of the midpalatal suture permits a larger correction than nonsurgical orthodontic treatment could achieve.

## Distraction strategies in cleft lip and palate

Distraction osteogenesis offers several advantages over conventional osteotomies in the treatment of patients who have cleft lip and palate. There is a reduced tendency for significant relapse after distraction of the maxilla than after traditional maxillary osteotomies. The soft tissue changes associated with maxillary advancement may be superior after distraction osteogenesis when compared with traditional LeFort I level advancement surgery [32]. It is also possible that deterioration of velopharyngeal function may be avoided in patients at risk for its development [2,14–16,33].

The midfacial deformities seen in patients who have cleft lip and palate include transverse maxillary deficiency, midfacial retrusion, and significant alveolar cleft defects. Transverse maxillary deficiency in a patient who has unilateral cleft lip and palate can be corrected with corticotomy and distraction in a modified procedure similar to the surgically assisted rapid palatal expansion or surgically assisted maxillary expansion technique.

Midfacial retrusion may be treated at the LeFort I, II, or III levels. LeFort I level distraction may involve advancement of segmentalized maxillary fragments or the entire maxilla [34,35]. Large alveolar cleft defects may be reduced in size using distraction osteogenesis to transport bone segments across the cleft [36]. Such a decrease in size of the cleft and associated oronasal fistula may enhance the outcome and predictability of bone grafting techniques [37].

Distraction hardware developed for anterior maxillary segmental advancement (Fig. 7A–E) has been used successfully in patients who have cleft lip and palate [38,39]. A stereolithic skull reconstructed from a three-dimensional CT scan can aid planning of such osteotomies by permitting preoperative selection and bending of plates, which reduce expenditures on distraction hardware and operating room time. Preoperative planning also ensures that a certain configuration and arrangement of the selected distraction hardware actually produce the vectors of distraction desired (Figs. 8–12).

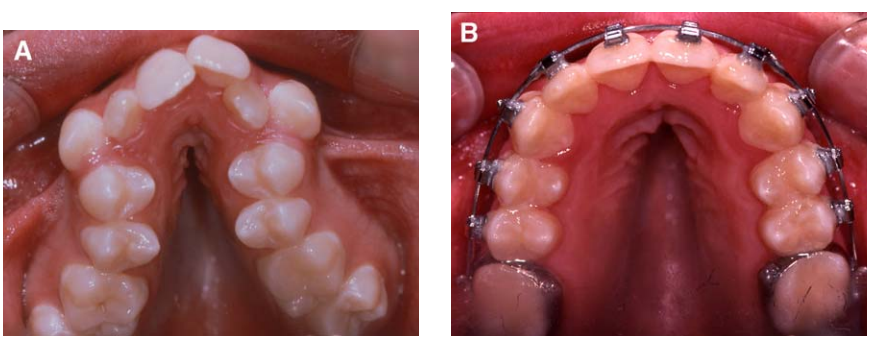


Fig. 6. (*A, B*) Constricted maxillary dental arch before and after surgically assisted rapid palatal expansion and orthodontic alignment.

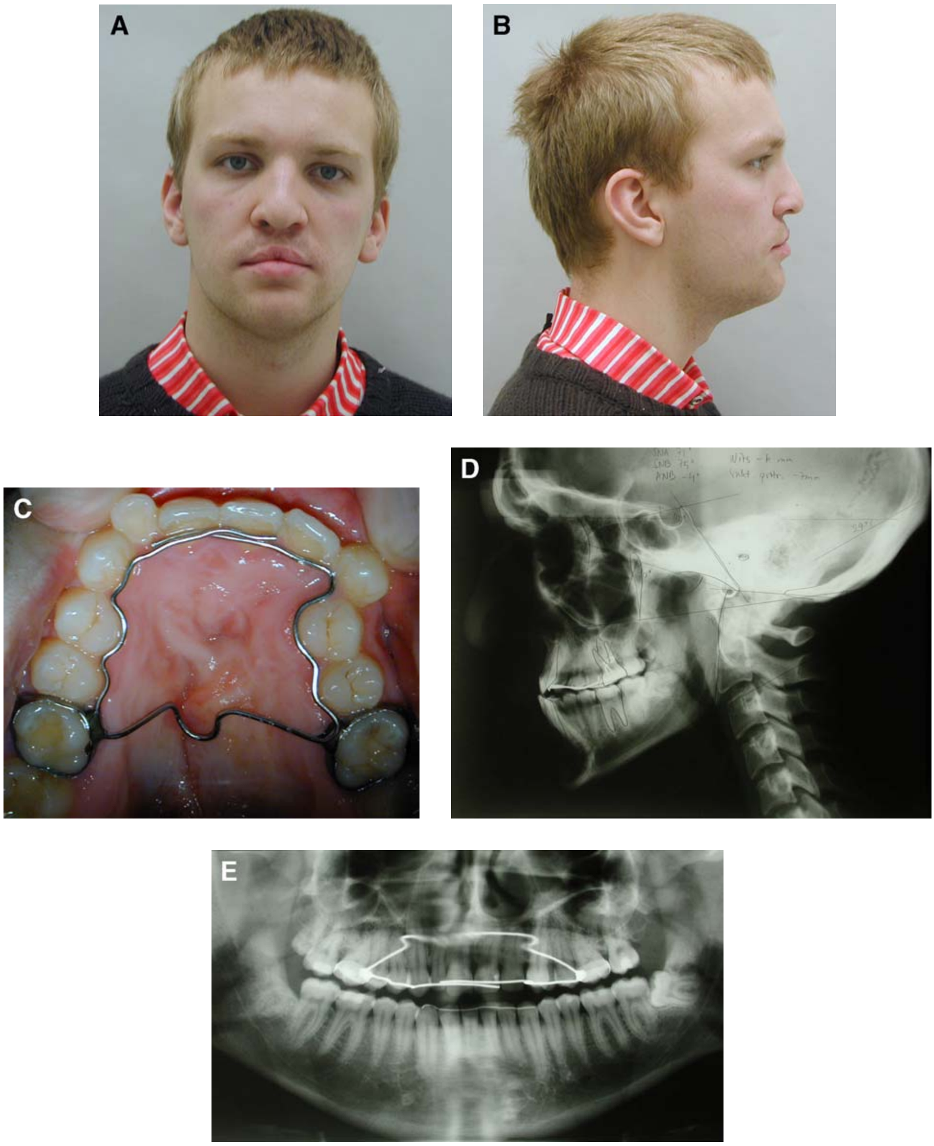


Fig. 7. Frontal (*A*) and lateral (*B*) view of 18-year-old man with bilateral cleft lip and palate and maxillary hypoplasia. (*C*) Extensive palatal scarring put the patient at risk for developing velopharyngeal insufficiency with traditional LeFort I maxillary advancement. Panoramic radiograph (*D*) and lateral cephalogram (*E*) of patient.

Distraction hardware also has been developed for LeFort I level osteotomies (Fig. 13A–C) in embodiments designed to be used submucosally and subcutaneously [40–42]. The selection of a specific device is determined by the goals of the distraction procedure, anatomic constraints, and the amount of room available to accommodate placement of the hardware. Care must be taken to avoid damaging the developing dental follicles or tooth roots when applying such devices to the lateral wall of the maxilla.

The initiation of midfacial distraction relative to creation of the corticotomy or osteotomy has been studied in growing sheep [43]. In primates, a protocol for immediate distraction that was composed of intraoperative device activation, 10 mm of acute distraction, and an additional 10 mm of distraction performed at a rate of 1 mm per day was compared with a protocol for delayed distraction that comprised a 5-day postoperative latency followed by a 20-mm distraction performed at a rate of 1 mm per day. There

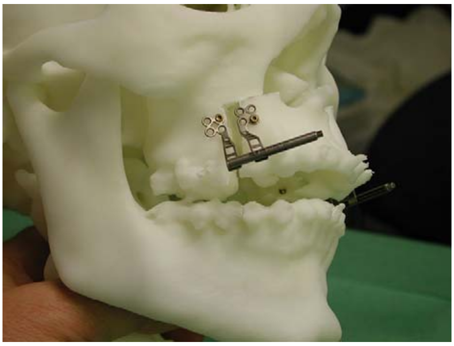

Fig. 8. Simulation of osteotomy, distractor placement, and advancement on stereolithic model.

was no evidence of relapse after immediate distraction or delayed distraction 6 months later. Neither were significant differences noted after either distraction protocol when the regenerated bone was examined histologically, ultrastructurally, or by dry skull analysis [44].

## High level LeFort distraction osteogenesis

The treatment of patients with craniosynostotic syndromes (eg, Crouzon [Fig. 14A–D], Apert, Pfeiffer, and Saethre-Chotzen) includes advancement of the midface [45]. Distraction osteogenesis can be performed at all levels of the midface [46–48], zygomatic bones [49], healed facial bone grafts [50], frontal bones [51], and other bones of the cranium [52,53]. Various distractor designs are available, but essentially they can be grouped into two basic categories [54–59]: external halo-like devices (see Fig. 1) and smaller internal devices (Figs. 15–18).

Proponents of external devices point out that although these devices are large and cumbersome, they are rigid and easily adjustable, often in more than one plane of space. External appliances permit easy control of the force and direction of distraction [55]. They can be applied easily to growing children, and they obviate the need for rigidly fixing devices on the lateral walls of the maxilla using screws where developing dental follicles and roots of the permanent dentition can be damaged. The use of these appliances is associated with the risk of the fixation pins penetrating the cranium, and pin site infections, however [56]. The social stigma associated with wearing an external device may deter its use. External devices also are prone to being accidentally dislodged [10].

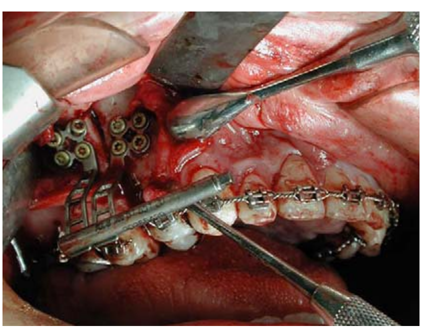

Fig. 9. Distraction device fixed in position on right maxilla.

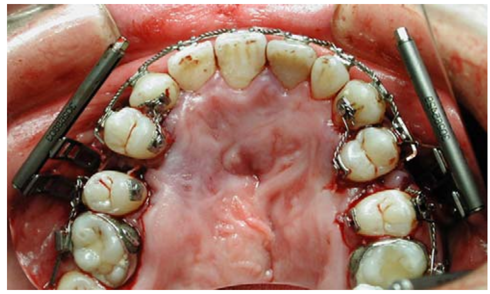

Fig. 10. Occlusal photographic view of palate shows vectors of distraction in a minimally convergent orientation.

Internal appliances are out of sight and have minimal impact on a patient's daily activities [59]. They are unidirectional, however, which makes distraction possible in only one plane of space. Often two internal devices must be used simultaneously on either side of the maxilla, which increases the chance for asymmetry and doubles the cost. Metal internal distraction devices are rigid but require removal after the distraction process, which can be difficult and complicated. Resorbable appliances that do not require removal recently have become available [60–62]. The tissues surrounding the transcutaneous distraction rods of the internal devices can become infected.

The results of maxillary distraction at the LeFort III level are far better than those of traditional midface advancement. Fearon [45] compared 12 children who had LeFort III distraction to an age-matched cohort of 10 children treated by osteotomy at the same level. The average horizontal advancement achieved in the LeFort III distraction group was 19 mm compared with 6 mm in the LeFort III osteotomy group. Two of the patients in the distraction group with obstructive sleep apnea demonstrated objective airway improvement and two further patients with obstructive sleep apnea were decannulated.

Fearon [45] used external and internal devices in his cohort of patients and preferred the aesthetic results accomplished using a halo over those obtained

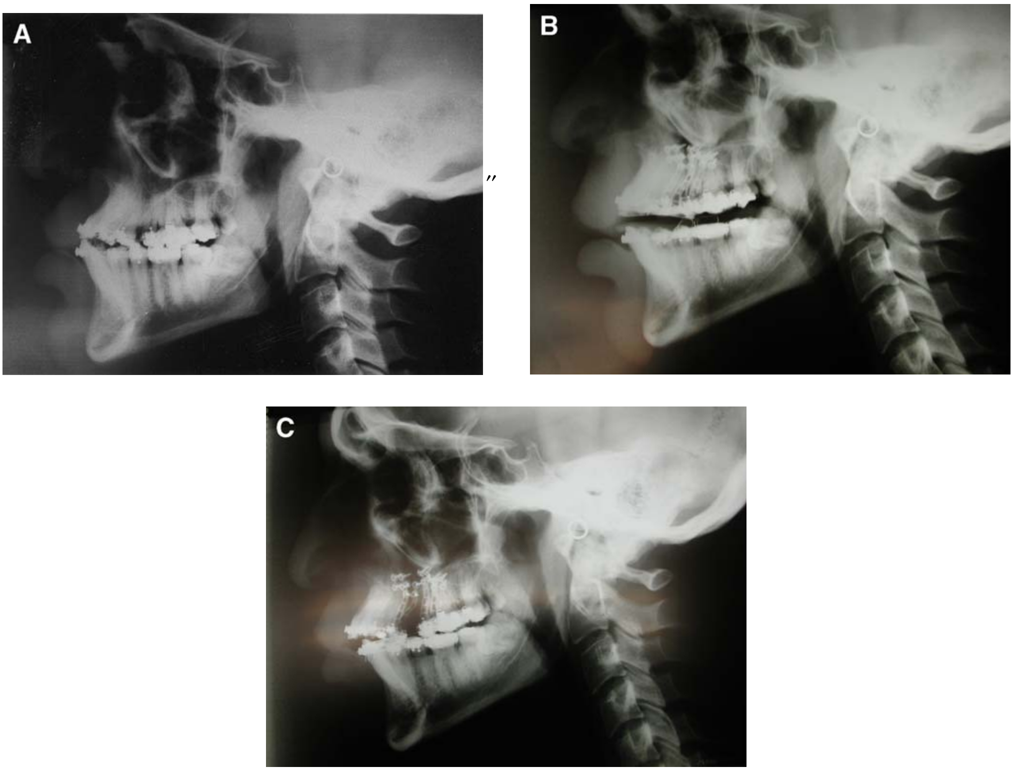


Fig. 11. (*A*) Preoperative lateral cephalogram. (*B*) Lateral cephalogram taken immediately after operation. (*C*) Lateral cephalogram taken at end of distraction phase, at beginning of consolidation phase. Note presence of bone gaps between roots of bicuspid teeth.

with internal distractors because the halo allows the vector of distraction to be focused on the facial midline, which helps to reposition the concave midface and provides a more convex facial profile.

Osteotomies can be tailored to the specific aesthetic and functional needs of a patient. Distraction osteogenesis can be executed at multiple levels to correct the occlusion and the midfacial retrusion independently using separate devices and vectors [63]. This is because the teeth, the nasofrontal region, and the orbital rims may not all advance the same distance (Fig. 18). Satoh and colleagues [63]

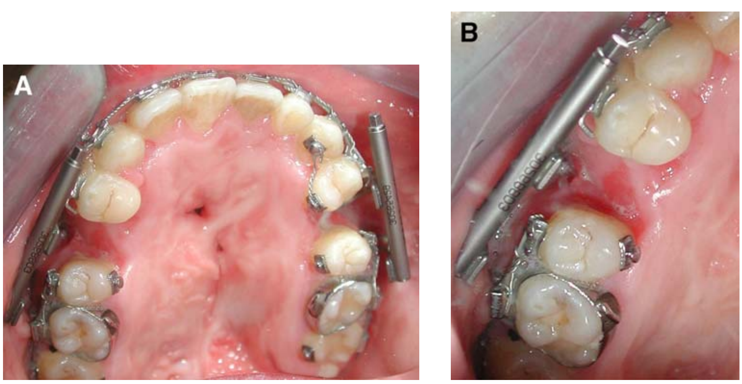


Fig. 12. (*A*) Palatal view of distractors in place. Note small fistula has opened on palate since beginning of distraction process. (*B*) Palatal view of right buccal segment shows distraction gap.

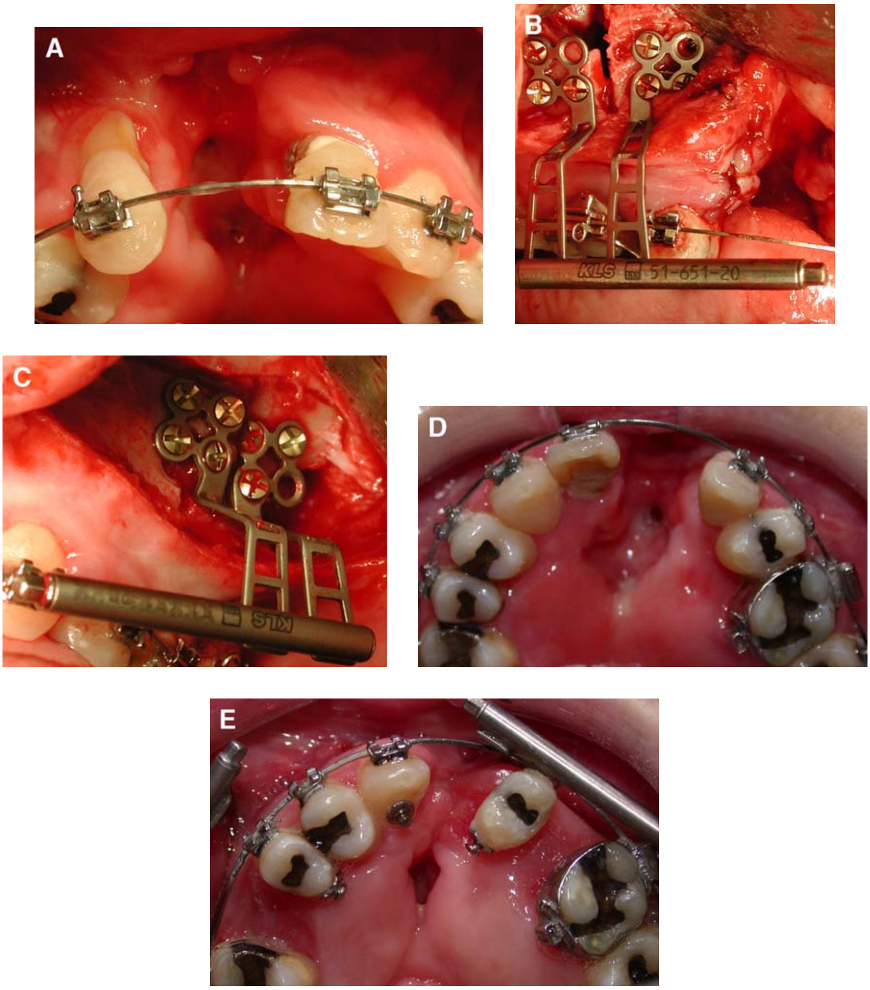

Fig. 13. (*A*) Anterior view of large alveolar cleft with oronasal fistula. (*B, C*) Internal distractor is applied to right and left osteotomized segment. (*D*) Occlusal view of alveolar defect preoperatively. Note two failing cleft adjacent teeth were removed before start of distraction. (*E*) Postoperative occlusal view of alveolar cleft and oronasal fistula, both of which have been reduced in size. More soft tissue is available for closure of oronasal fistula and reconstruction of alveolar defect.

recommend that the final position of the midface be governed subjectively by the position of the nasal bones, malar complexes, and orbital rims relative to the rest of the face [45,63], whereas the occlusion should be governed by an occlusal splint [63]. They also recommend osteotomizing the midface into two portions and distracting them separately using independent vectors and different amounts of distraction [63].

## Alveolar distraction in the maxilla

Congenital absence of teeth (eg, oligodontia and alveolar clefting) is usually accompanied by bony defects of the maxillary alveolus. Acquired bony defects occur after tooth extraction, periodontal disease, maxillofacial trauma, and tumor ablation. The configuration of alveolar defects can be primarily horizontal or vertical in nature—or a combination of each—and can limit the restoration of missing teeth with dental implants.

The treatment of alveolar defects includes guided bone regeneration using various membranes, onlay autogenous bone grafts, connective tissue grafts, and alloplastic augmentation. Vertical alveolar defects are difficult to overcome in a predictable manner using autogenous bone grafts, and they often lead to aesthetic shortcomings [64,65]. Distraction osteogenesis

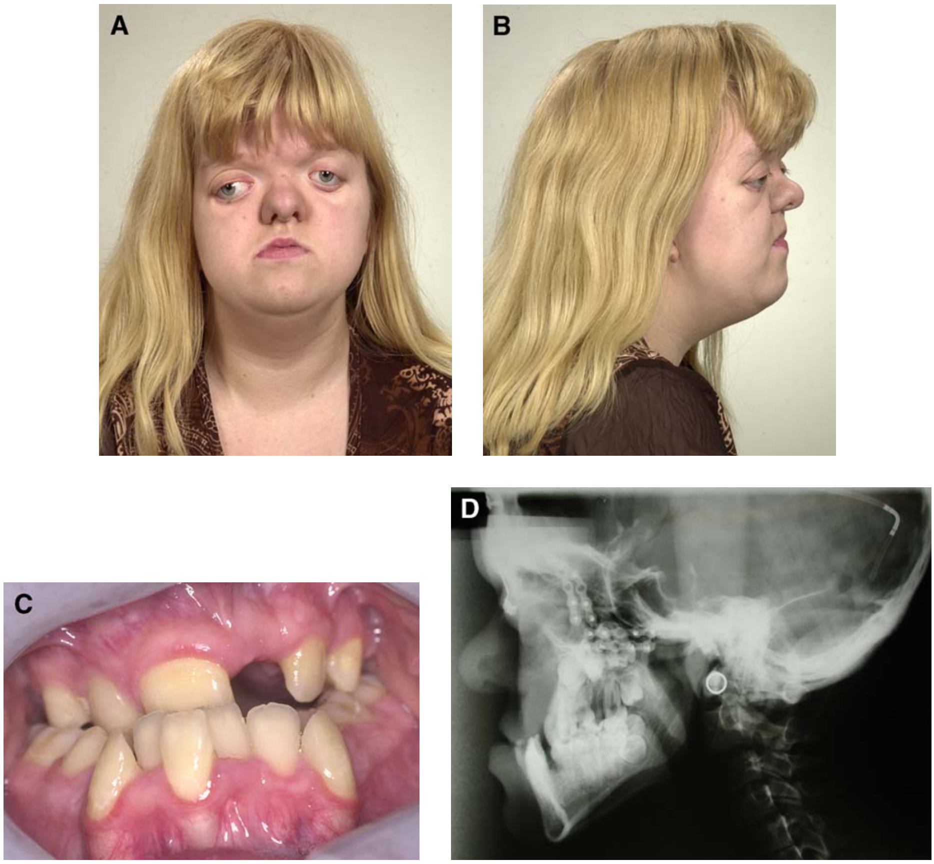


Fig. 14. Frontal (*A*) and lateral (*B*) view of 16-year-old girl with Crouzon syndrome and midface retrusion. (*C*) Occlusal view demonstrates severely retrusive maxilla and crowded dentition. (*D*) Lateral cephalogram shows significant midfacial retrusion despite previous osteotomy to advance the midface.

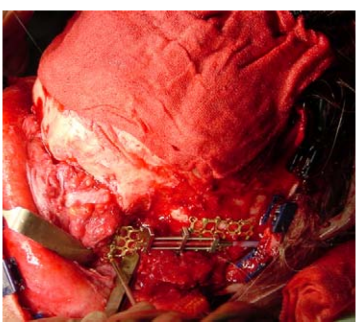

Fig. 15. Position of distraction devices after LeFort III osteotomy. Note foot plate secured below (frontozygomatic) osteotomy along lateral orbital wall and on temporal bone.

of the maxillary alveolus permits correction of alveolar defects often without the use of a bone graft.

Alveolar distraction osteogenesis may offer several advantages over bone grafting alone in the treatment of vertical alveolar defects because no donor site is required, distraction of bone and surrounding soft tissue occurs simultaneously, the transport segment is a form of pedicled graft that is never separated from its blood supply, and it has the potential for better control of vertical height, aesthetics, and biomechanical loading [66,67].

Alveolar distraction devices have three basic components: an upper member, a distraction rod, and a lower member/baseplate that supports the vertical force of distraction. These devices can be classified as intraosseous or extraosseous, uni-, bi- or multidirectional, nonresorbable or resorbable (ie, they do not require a second surgery to remove distractor components), and prosthetic (ie, they can remain in place to be used to support the dental

Fig. 16. Immediate postoperative anteroposterior cephalogram before onset of distraction phase.

Fig. 18. Post-consolidation lateral cephalogram. Advancement at incisal level was 19 mm and 8 mm at frontonasal region.

prosthesis) or nonprosthetic (ie, they must be removed after distraction and replaced with a dental implant) [68,69].

Alveolar distraction osteogenesis is indicated for the treatment of alveolar defects in which the alveolar processes are atrophic and deficient. Alveolar distraction osteogenesis also can be used to correct vertical defects caused by ankylosis and submergence of primary teeth retained in the absence of succedaneous teeth (Fig. 19). Alveolar distraction osteogenesis is contraindicated in cases of severe atrophy in which there is insufficient bone to allow safe hardware placement between tooth roots and the floor of the nose or maxillary sinus. It also may be contraindicated in patients who have severe osteopo-

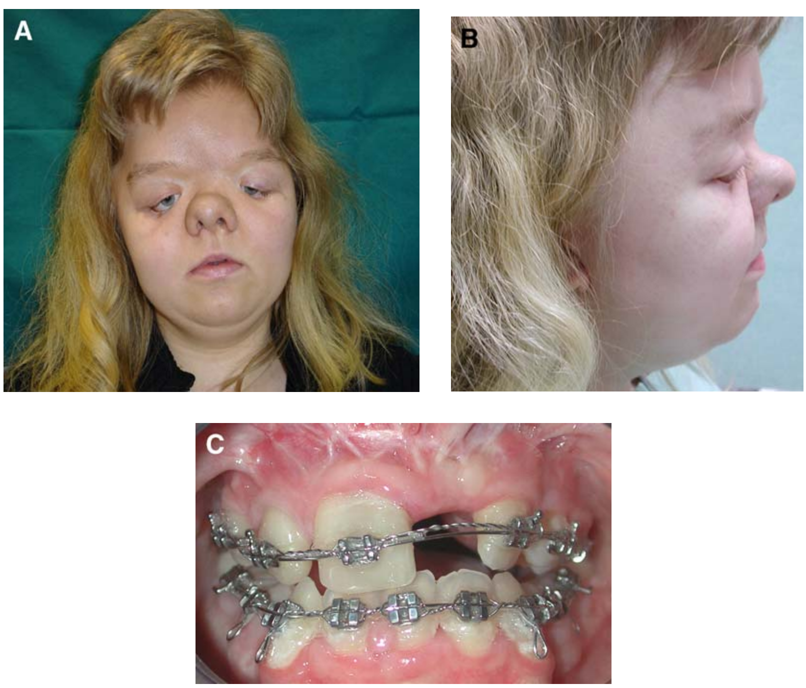


Fig. 17. Frontal (*A*) and lateral (*B*) view of patient at end of consolidation phase of distraction. (*C*) Postoperative occlusion with correction of anterior crossbite.

Fig. 19. Ankylosed deciduous teeth are useful anchorage units for attachment of tooth-borne distraction devices. Note submergence of deciduous lateral incisors and canines. There is a vertical discrepancy in the alveolus, which required vertical distraction osteogenesis before dental implant restoration.

rosis in which bone quality is poor, in patients of extremely advanced age, or in patients who are unlikely to demonstrate compliance with the rigors of the distraction process. The first step in alveolar distraction is to plan the vector of distraction and select a distractor that is capable of delivering that force in the proper direction. If teeth are available to anchor a distraction device then an external tooth-borne device can be used (Figs. 20, 21A–C); otherwise, an internal bone-borne device must be selected. The effect of the rigid palatal tissues on the vector of distraction should be kept in mind when treating the maxilla. Palatal tissues tend to exert pull on the distracting segment and cause it to tilt lingually away from the desired vector. If ankylosed teeth are used for anchorage of the distraction segment, they are extracted after the removal of the distraction hardware (Fig. 21C). Dental implants can be placed into the distracted alveolar segment and restored in their new ideal position (Fig. 22).

## The distracting dental implant

There are clear advantages to having a device that can be used to correct vertical bony defects and can serve as the anchor for a prosthesis after completion of distraction. Such an intraosseous, prosthetic distraction device with completely internalized components is currently in the prototype stage of development (Fig. 23). The distracting implant, which is composed of a fixture connected to a footing by means of a retaining screw, is placed within the bone. When the assembly is installed completely, the proximal surface of the footing bears against the bottom of the osteotomy. After the completion of the distraction process (Fig. 24), the distracting dental implant is used to support a dental prosthesis.

## Description of the alveolar distraction process using dental implants

The first step in alveolar distraction osteogenesis using a dental implant is assessment of the nature of the bony defect. The distracting dental implant should be used in a vertical defect up to 5 mm in which there is sufficient bone to distract without bone grafting. Alveolar defects with up to 10 mm of vertical loss in which there is significant horizontal loss may require bone grafting for width followed by healing before distraction.

Distracting dental implantation is a two-stage procedure in which the implant is placed and permitted to heal for some months before the distraction procedure commences. When sufficient osseointegration of the fixture and the footing have occurred, a corticotomy using an oscillating saw or bone chisel is completed. After a latency period of 5 to 12 days, active distraction is started. To commence the distraction procedure, the retaining screw is removed and the distractor rod is placed within the fixture (Fig. 24). The distractor rod is advanced along the bore of the fixture until it bears against the footing. Further rotation of the distractor rod results in the fixture moving in the distal direction relative to the footing. The segment of bone into which the fixture is integrated moves in the direction of

Fig. 20. Anterior view of tooth-borne distraction apparatus to vertically lengthen maxillary alveolus.

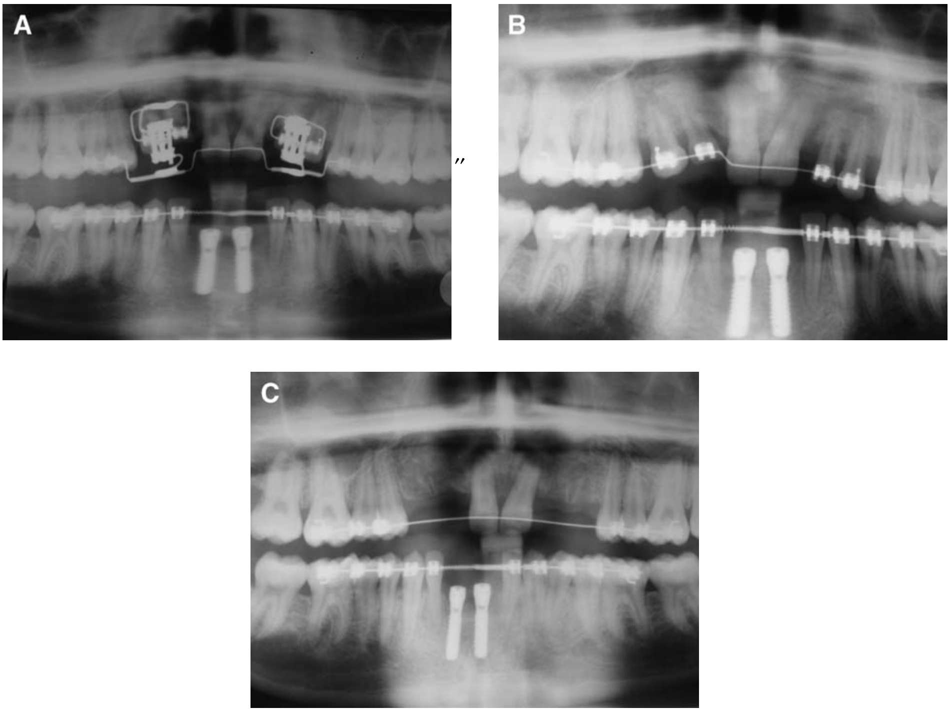


Fig. 21. (*A*) Immediate postoperative panoramic radiograph shows device position. (*B*) Panoramic radiograph after distraction device removed shows increased vertical height of alveolus and teeth. (*C*) Panoramic radiograph after extraction of deciduous teeth shows increased vertical height of alveolus.

distraction [3,4]. Depending on the length of travel along the direction of distraction, one or more distractor rods of different lengths may be used inside the implant.

Final bone healing occurs during the consolidation period. The distractor or an external support, such as orthodontic splinting, is used to stabilize the segments. Thereafter, the distractor rod is removed, which leaves a cylindrical void in the newly formed bone that also fills in with bone. Upon completion of the distraction, the fixture may remain in place, having been firmly integrated in the bone tissue, where it can be used to serve as an anchor for a prosthetic crown or bridge. With the advent of new titanium surface geometries and concomitant use of growth factors, more rapidly developing osseointe-

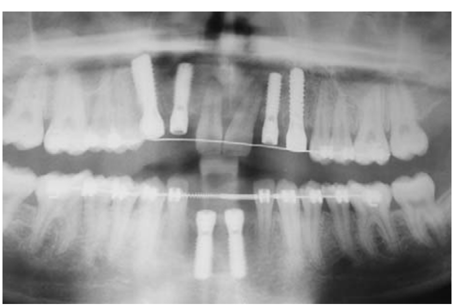

Fig. 22. Panoramic radiograph after implant fixture placement.

Fig. 23. Distracting dental implant including fixture body, distractor rod, and footplate represented by clear plastic disc next to implant (CSMT, Mississauga, Ontario, Canada).

Fig. 24. Distracting dental implant activated demonstrates gradual gains in vertical alveolar height. Distracting hardware also serves as prosthetic restoration.

gration may allow for implant placement and distraction in a single stage.

## Guidance of implant placement

Although the distracting dental implant is a unidirectional distraction device, its trajectory can be guided to a certain extent using orthodontic forces or a prosthodontic docking station. A further consequence of the unidirectional nature of the distracting dental implant is that the vector of distraction is defined primarily by the implant's longitudinal axis. To a certain extent, the geometry of the corticotomy can be designed to counter pull from the lingual or palatal mucoperiosteum. Because the trajectory of the distracting implant depends substantially on the vector of distraction, it is critically important to control the spatial location and axial inclination of the implant. An implant positioning device with the capability of controlling spatial location and axial inclination is currently under development.

## The future of alveolar and midface distraction osteogenesis

Distraction osteogenesis is a powerful technique that already has revolutionized pediatric oral and maxillofacial surgery by providing a means of reliably lengthening the bones of the midface and mandible [48]. As an alternative or an adjunct to conventional ridge augmentation procedures, alveolar distraction osteogenesis with a distracting dental implant offers the prospect of greater control in the correction of vertical alveolar defects and better aesthetic outcomes. A distracting implant also allows for correction of some unsuccessful results that otherwise might require the use of long clinical crowns or pink porcelain, or, in the worst case, removal of the implant, revisional ridge augmentation, and reimplantation.

Distraction osteogenesis may allow for earlier implant placement in children. The most appropriate time for implant placement in growing patients has been discussed. Experiments designed to study the effect of dental implants on dentoalveolar growth and development in pigs demonstrated that implants remain stationary and do not erupt together with adjacent teeth [70]. Implants were found to inhibit local growth and development of the alveolar process, much in the same way that ankylosed teeth behave [71]. A 3-year prospective clinical study in adolescents with congenitally missing teeth verified that implants do not move during jaw growth and result in development of an infraocclusion and vertical marginal discrepancy of the prosthetic crown that is proportional to the amount of residual jaw growth after implant restoration [71,72]. One case report [73] documented a similar phenomenon occurring over a decade in an adult, putatively caused by continuing growth of the facial skeleton [74–76].

Standardization of implant capability to permit distraction osteogenesis would extend the ability to refine aesthetics in the future after late detrimental changes related to residual alveolar growth, continued growth of the dentoalveolar process through adulthood, eruption of adjacent teeth, and recession of soft tissue.

In the future, distraction osteogenesis may benefit from automation of the distraction technique by the incorporation of a micromotor controlled by a microprocessor to allow for smooth and continuous distraction. Three-dimensional treatment planning with accurate transfer will allow for proper placement of the bony segments in three dimensions. Endoscopy may be another future adjunct to the distraction procedure to facilitate minimally invasive surgery with improved visualization of the osteotomy sites [77].

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